TO: Randy Segawa, Environmental Program Manager (Supervisor) I
Environmental Monitoring Branch

FROM: Terrell Barry, Ph.D., Research Scientist III *Original signed by*
Bruce Johnson Ph.D., Research Scientist III *Original signed by*
Environmental Monitoring Branch
(916) 324-4140

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SUBJECT: ANALYSIS OF THE RELATIONSHIP BETWEEN PERCENTILES OF THE WHOLE FIELD BUFFER ZONE DISTRIBUTION AND THE MAXIMUM DIRECTION BUFFER ZONE DISTRIBUTION

Background

In 1992 the Department of Pesticide Regulation (DPR) first implemented the use of air dispersion modeling in the development of mitigation measures for bystander exposure to methyl bromide. The initial buffer zone development employed screening level modeling techniques, including standard weather conditions, square field geometry, and 24 hour time weighted average (TWA) flux (Johnson 1999, Johnson and Barry 2005, Segawa et al. 2000). The buffer zones developed were approximately 95% protective on an individual application basis (Johnson, 2001). This means that for any given application, the probability that the TWA concentration at the buffer zone distance would exceed a specified exposure threshold anywhere around the field perimeter was approximately 5%.

In recent years, with the development of probabilistic modeling packages (PERFUM [Reiss and Griffin, 2006]; FEMS [Sullivan et al., 2004]; SOFEA [Cryer, 2005]), distributions of buffer zones for various application scenarios have been produced using five year sets of meteorological data. As explained later, a buffer zone length at a particular percentile of the distribution insures coverage at a level of protection (protection probability) equal to that percentile. This technique of selecting a buffer zone length that corresponds to a desired protection probability from a distribution of lengths is now one of the most important air dispersion modeling based mitigation tools. However, two very different methods have been used to construct distributions of buffer zone lengths for specific use scenarios. Even though the resulting buffer zone distributions represent fundamentally different philosophies of risk mitigation and are not equivalent, the terminology used to describe the protection probability is the same. Consequently, there is substantial confusion over the meaning of "protection probability" and related concepts with these different methods.

The two methods for constructing a distribution of buffer zone lengths are known as the "whole field" method and the "maximum direction" method. The general modeling procedure used to determine the buffer zone distributions for either the maximum direction or whole field method starts with a given fumigant flux versus time function ("flux profile", e.g. Figure 1), which describes the course of emissions following an application. For a specific scenario the size of the field is fixed, as is the application rate. What varies from simulation to simulation is the meteorology used to calculate the downwind air concentrations. The downwind air concentrations are averaged over the appropriate exposure time (also called the threshold averaging period). The threshold averaging period and the threshold concentration (or reference concentration) is fumigant specific. For example, the DPR methyl bromide threshold averaging time is 24 hours and the DPR threshold concentration is 815 ug/m^3 as a 24-hr time TWA. In each period, the concentration isopleths generated by the model are compared to the concentration exposure threshold (for example, 815 ug/m^3 for methyl bromide). Buffer zones are determined by the distance from the field edge to where the threshold concentration occurs. Thus, the resulting buffer zone distributions reflect the variations in period-to-period meteorology.

For both methods discrete directions are represented as "spokes" emanating outward from the center of the field (e.g. Figure 2), and are defined by the discretization scheme used in the modeling procedure. However, for the maximum direction method, the comparison of concentrations on each spoke yields a single distance that is equal to the maximum distance at which the modeled TWA concentration is equal to the exposure threshold. This procedure is repeated over the length of the meteorology record and the distances are compiled to obtain a distribution. For example, for methyl bromide and using a 24 hour threshold averaging time, each day (24 hours) of simulation yields a single buffer zone estimate. In this case a 5 year simulation would provide approximately 365 x 5 = 1825 daily, maximum buffer zones which would be compiled to form a distribution. The number is approximate because meteorological data sets may be incomplete.

In contrast, the whole field method compiles distances in every direction around the field during each threshold averaging period for each simulation. The number of distances selected in each averaging period is equal to the number of spokes, and each selected distance is equal to the distance along the spoke where the modeled TWA concentration equaled the exposure threshold. Then, similar to the maximum direction method, the procedure is repeated over the length of the meteorology record to generate the whole field buffer zone distribution. For example, a single threshold averaging period simulation for methyl bromide (24-hour) would yield 200 buffer zone estimates (if the field had 200 spokes). The maximum of the 200 buffer zone estimates is the maximum direction buffer zone distance for that day. The remaining 199 estimates will generally be less than the maximum. In the whole field method, all 200 daily buffer zone estimates are compiled from each day to form the distribution. This results in approximately
365 x 5 x 200 = 365,000 estimates.

In developing fumigant buffer zones by both the screening approach and the probabilistic approach, DPR has controlled protection probabilities at the individual application level (Segawa et al. 2000, Johnson, 2001, Barry, 2006). To do this, for each threshold averaging period the single point farthest away from an application where the threshold concentration occurs determines the buffer zone for each realization of an application scenario. For example, over the long term, a buffer zone selected to be “95%” protective for a 24 hour TWA threshold will be long enough to capture the threshold air concentration everywhere around the perimeter of the field for 95% of all applications. Thus, on average over thousands of realizations, for every 100 applications, the buffer zone will be large enough for 95 of those applications–the buffer zone achieves the protection goal. However, 5 of those 100 applications will show air concentrations at the buffer zone that exceed the threshold air concentration. Thus, the buffer zone fails to achieve the protection goal at some locations around the perimeter of the field. This “maximum direction buffer zone” method (Reiss and Griffin, 2006) of constructing the protection probability controls individual application risk. Barry and Johnson (2005) previously verified the PERFUM maximum direction buffer zone protection probabilities.

While the whole field approach (Reiss and Griffin, 2006) employs the same general modeling procedure as the maximum direction method, the whole field buffer zone distributions are constructed using distances to the threshold air concentration in every direction around the field during each averaging period. Thus, the whole field approach includes in its distributions distances which are predominantly upwind and, therefore, small. The whole field buffer zone percentiles are equal to the probability that the TWA concentration is less than or equal to the threshold at any random location along the edge of the buffer zone of a random application. The whole field buffer zone percentiles do not correspond to a specified level of protection at the individual application level. Therefore it is important to determine the relationship between the maximum direction and whole field approaches in terms of the per application failure rate.

If risk managers are to make fully informed decisions, the method with which the protection probability is constructed must be completely transparent and well understood. The objective of this memorandum is four fold: (1) to describe procedures and assumptions used to derive the PERFUM whole field and maximum direction buffer zone distributions, (2) to provide a transparent comparison of the whole field method protection probabilities to the equivalent maximum direction protection probabilities using actual model fumigant datasets, (3) to verify in a specific scenario PERFUM2 calculations, and (4) to estimate in a specific scenario the distribution of perimeter fractions amongst days where the buffer zone was not protective. Our intent is to provide risk managers and stakeholders with a technical analysis that assists the process of risk mitigation.

Methods

Two types of data were used in this analysis to characterize the relationship between the maximum direction protection probability and the whole field protection probability: (1) Data collected from PERFUM outputs for modeling conducted by the U.S. Environmental Protection Agency (EPA) and (2) data calculated using PERFUM code modified to provide air concentration and buffer zone outputs not available from the distributed model.

Data collected from the USEPA PERFUM modeling outputs

PERFUM modeling results were obtained from U.S. EPA as part of the materials DPR staff reviewed related to U.S. EPA fumigant risk assessments. For the present analysis, PERFUM outputs for various soil applications of methyl bromide, chloropicrin and metam sodium under various meteorological data sets were used to assemble a database containing the 99th percentile (99%) whole field buffer zone length and its equivalent maximum direction percentile (rounded to the nearest 1%). The equivalent maximum direction percentile is the percentile of the maximum direction buffer zone distribution that corresponds to a buffer zone equal to the 99% whole field buffer zone length, and is numerically equal to the individual application level maximum direction protection probability. This procedure is illustrated graphically in Appendix F. The five meteorological data sets (locations) were: (1) Ventura, California, (2) Bakersfield, California, (3) Tallahassee, Florida, (4) Yakima, Washington, and (5) Flint, Michigan. Simulations were conducted at maximum application rates and differing application methods, specific to each fumigant. Comparisons between the 99% whole field buffer zones and the equivalent maximum direction percentiles are presented graphically and statistical summaries are included.

The objective was to characterize the relationship between the 99% whole field buffer zone length and its equivalent maximum direction buffer zone length distribution percentile over field sizes of 5, 20, and 40 acres. However, a significant limitation is the PERFUM 1440m upper limit on buffer zone length output. Because it is not possible to estimate percentiles for buffer zone lengths generated by PERFUM which are at or exceed 1440m, it was necessary to exclude from this analysis those fumigant application method, rate and size combinations that would produce large buffer zones which exceeded 1440m. Therefore, this analysis cannot fully characterize the relationship between the 99% whole field buffer zone distributions and the maximum direction buffer zone distributions.

PERFUM Code Modification

Modifications were made to the PERFUM2 source code in order to externally record internally generated values of interest (more on the modifications below). Using this modified code, 2 pesticide application situations were studied: 5 acre with fine grid and 20 acres with fine grid. The application scenario was shallow shank injection, tarped methyl bromide application using the maximum application rate of 430 lbs/acre. The flux profile is shown in Figure 1. While two 24-hour periods were included in the flux profile, the analysis focused on the first 24-hour period, which was the highest flux period. A listing of the PERFUM2 input file for 20 acres is shown in Appendix A. Ventura meteorology was used, though one day was removed due to a string of 24 hours of calms.

The PERFUM2.FOR source code was modified to print out daily concentrations ordered by both spoke/ring and spoke-specific buffer information. The modifications were exclusively in the subroutine “DAYCALC”, which is contained in the PERFUM2.FOR file. The modifications are described more fully in Appendix B and a FORTRAN source code listing showing the modifications is presented in Appendix C. Briefly, code was inserted to open files and write out internal values. The code modifications did not change the logic or calculations of the program.

These modifications in the subroutine DAYCALC provided output which enabled (1) verification of the individual concentrations averages generated by PERFUM2, (2) analysis of the number of spokes each day where the reference concentration was exceeded along that spoke at the buffer zone distance, (3) verification of the 99% whole field buffer distance, and (4) further analysis of the fraction of the perimeter at the buffer zone distance where the health reference concentration would be exceeded. For (1) a single day was chosen, an independent ISCST3 control file was created and the discrete receptor concentrations from the single-day independent run were compared to the corresponding concentrations from PERFUM2 as found in CONCEN.OUT. For (2) the 99% whole-field buffer zone was compared to each spoke-specific buffer zone each day. The daily spoke exceedance information was used to estimate a daily fraction of the buffer perimeter where the reference concentration was exceeded. These daily lengths were compiled into a distribution. For (3) the individual spoke length “buffers” (distance to reach the reference concentration) were aggregated into a distribution and distributional points were compared to the PERFUM2 distribution points. For (4) an additional program was written to analyze output from the modified PERFUM2 to calculate a fraction of the perimeter where concentrations exceeded the reference concentration.

For days on which concentrations along the buffer zone exceeded the reference concentration, we calculated the fraction of the perimeter that exceeded the reference concentration with two methods: by a simple count of exceedance spokes divided by total spokes and by an edge/corner spoke perimeter calculation that adjusted for the different arc-length represented by the edge versus corner spokes. There was no substantive difference in these results, so the perimeter calculations based on the more accurate arc-length are presented. In this discussion, the edge/corner spoke method is the same as the arc-length method. Appendix D lists a FORTRAN utility which estimated the fraction of perimeter at the buffer zone distance where the threshold concentration was exceeded and Appendix E presents results comparing the two methods for computing the perimeter distances where the threshold concentration was exceeded.

Results

Data collected from the USEPA PERFUM modeling outputs

Figures 3 through 5 show the change in the equivalent maximum direction buffer zone distribution percentile with the 99% whole field buffer zone length. The three figures are on the same scale to facilitate cross comparison. For methyl bromide (Figure 3) the equivalent maximum direction percentiles are clustered between about 85% and 90%. For metam sodium (Figure 4) and chloropicrin (Figure 5), the equivalent maximum direction percentiles show a greater range, from about 95% to 63%. There are several factors potentially contributing to differences observed between fumigants. The most significant factor may be the averaging time of the health threshold. The methyl bromide averaging time is 24 hours, the metam sodium averaging time is 8 hours, and the chloropicrin averaging time is 4 hours. It should be noted that the health threshold air concentration for metam sodium applications is actually for methyl isothiocyanate, which is a breakdown product of metam sodium and the contaminant of concern. An additional factor is that the 4-hr and 8-hr TWA whole field buffer zones with the lowest maximum direction buffer equivalent percentile occurred at night. Thus, shorter threshold averaging time coupled with a flux profile that caused the whole field buffer zone size to be driven by nighttime averaging periods was associated with the lowest maximum buffer zone equivalent percentiles.

Figure 6 summarizes the relationship between the 99% whole field buffer zone length and the equivalent percentile in the maximum direction buffer zone distributions for application methods used to apply the three fumigants. Figure 6 shows the distribution of maximum direction buffer zone percentiles with the median value labeled for each application scenario. The width of the box plots illustrates the variability for each application method in the equivalent maximum direction distribution percentiles. The methyl bromide 99% whole field buffer zones are the least variable with consistent median maximum direction buffer zone percentiles of 86 to 88. Thus, under the use scenarios characterized in this analysis on average about 12% to 14% of methyl bromide applications with a 99% whole field buffer zone will have a buffer zone failure somewhere along the whole field buffer zone perimeter. Figure 6 clearly shows variable performance of the 99% whole field buffer zones for metam sodium and chloropicrin. The median equivalent maximum direction percentiles vary between a high of the 92.5 and a low of 71. In addition to the large spread in the median equivalent maximum direction percentile for metam sodium and chloropicrin application methods, the variability within any particular application method is also quite different. For example, the metam sodium intermittent sprinkler and intermittent shank methods show very little variation and median equivalent maximum direction buffer zone percentiles of 91% and 92.5% respectively. In contrast, chloropicrin untarped broadcast and untarped bed methods show highly variable equivalent maximum direction buffer zone percentiles with median percentiles of 71% and 74.5%, respectively.

PERFUM Code Modification

Verifications. The single day verification showed complete agreement between the PERFUM2-generated concentrations and those from an independent ISCST3 run. The independently assembled distributions of whole-field buffer zone lengths yielded a 99% whole field buffer zone which agreed with the PERFUM2 99% whole field buffer zone for the 5 acre and 20 acre find grid scenarios. There was a minor difference in that PERFUM2 appears to round the estimated buffer zones to the nearest 5m. These verifications provide additional confidence in the PERFUM2 calculations.

Distributions of exceedance perimeter lengths. From the total 1794 days simulated, the 99% whole field buffer was not protective at some point along the perimeter of the buffer zone distance from the field on 271 days and 230 days for the 5 acre and 20 acre fields, respectively. Thus the 99% whole field buffer corresponded to an 85%-tile (=100*(1794-271)/1794) and 87%-tile (=100*(1794-230)/1794) maximum direction buffer for the 5 and 20 acre scenarios, respectively. These independently derived calculations were consistent with the results in Figure 6 for methyl bromide method 1.

Amongst the days where exceedances occurred, Figures 7 and 8 provide distributions for the fraction of the buffer zone perimeter based on the arc-length method which exceeded the reference concentration. The two methods for calculating the fraction yielded somewhat different histograms, but the general limits and shapes were similar (details in Appendix E). In both cases perimeter fractions ranged from 0.01 to about 0.15. In part, the differences between the 2 methods resulted from the different number of edge versus corner spokes between 5 acre and 20 acres fields and the relatively different arc lengths represented by the 5 acre and 20 acre cases.

The histograms in Figures 7 and 8 provide some indication of the distribution of fractions of perimeters which are exceeded, when there is an exceedance somewhere along the buffer zone perimeter. Figures 9 and 10 provide the same data expressed as cumulative distributions of perimeter exceedance fractions and can be utilized more quantitatively to calculate probabilities.

Thus, for example, for the 20 acre field, amongst days when there is an exceedance, the probability is about 50% that the length along the buffer zone distance perimeter will be greater than about 7% of the perimeter, using the arc-length perimeter calculation method (Figure 10).

Given that the 20 acre buffer perimeter for a 99% whole field buffer of 200m is 2,395m, there will be a 50% probability that the distance of exceedance along the buffer perimeter is greater than 168m.

Discussion

The 99% whole field buffer zones show median equivalent maximum direction buffer zone percentile levels of between 71% and 92.5% (Figure 6). Thus, the individual application 99% whole field buffer zone median failure rate is between 7.5% and 29% of applications. The highest failure rate of 37% was for chloropicrin broadcast untarp application method at Tallahassee, Florida.

The failure rate appears to be related to the averaging time of the health threshold. Shorter averaging times show higher individual application failure rates. Thus, the per application buffer zone failure rate determined using the 99% whole field method (ostensibly a 1% failure rate) results in maximum direction median failure rates of between 7.5% and 29% of applications. These results are for application scenarios where both the whole field and the maximum direction buffer zones are less than or equal to 1440m. Performance of large (>1440m) 99% whole field buffer zones is unknown.

For the 20 acre methyl bromide application example that we analyzed, when there is a failure, the data extracted from PERFUM indicates that the perimeter distances along which the health reference level is exceeded can be larger than the length of a football field. We would expect that varying field size, flux profile, or exposure period would influence the shape of the distributions in Figures 7-10 and hence, influence the size of the expected perimeter lengths which would be expected to experience concentrations higher than the reference level.

While the “whole field” method (Reiss and Griffin, 2006) has the stated objective of characterizing “whole population” risk, that method does not incorporate a numeric or spatial distribution of potentially exposed bystander populations. Consequently the whole field method does not explicitly incorporate the probability that bystanders are located on or near the buffer zone perimeter. The implicit assumption is that the probability is low and uniformly distributed around the field (Freeman, 2004). However, analysis of DPR soil application methyl bromide worksite plans (Barry, 2005) shows approximately 20% of applications have at least one sensitive site (e.g., residences, high schools) within 50ft of the buffer zone. The majority of applications showed between 1 and 10 sensitive sites and fewer showed between 10 and 50 or more (e.g. larger residential developments).

Summary

- The relationship between maximum direction and whole field buffer zone procedures was studied.

- The 99% whole field buffer zones corresponded to median equivalent maximum direction percentiles of 71% to 92.5%. This corresponds to a median individual application buffer zone failure rate of between 7.5% and 29%. The highest individual application buffer zone failure rate was 37% for the chloropicrin broadcast untarp application method at Tallahassee, Florida.

- Metam sodium and chloropicrin exhibited a wider range of equivalent percentiles than methyl bromide due to the shorter exposure threshold periods.

- Additional verification of PERFUM2 calculations was satisfactory.

- For a 20 acre methyl bromide shallow tarped scenario, amongst days where a 99% whole field buffer was exceeded, there was a 50% probability that the length of the perimeter that was exceeded would be greater than 168m.

- The whole field method does not take into account specific population locations and in California, residential development can be found next to approximately 20% of treated fields at the buffer zone distance.

References

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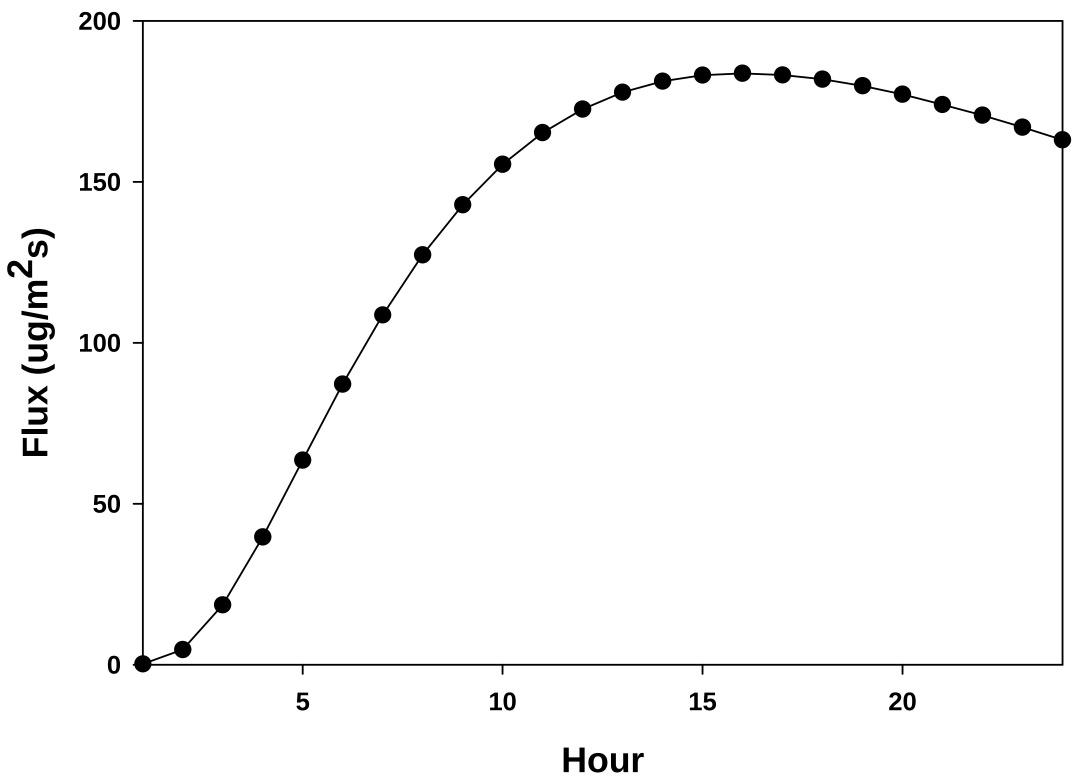


Figure 1. Flux profile for methyl bromide for first 24 hours.

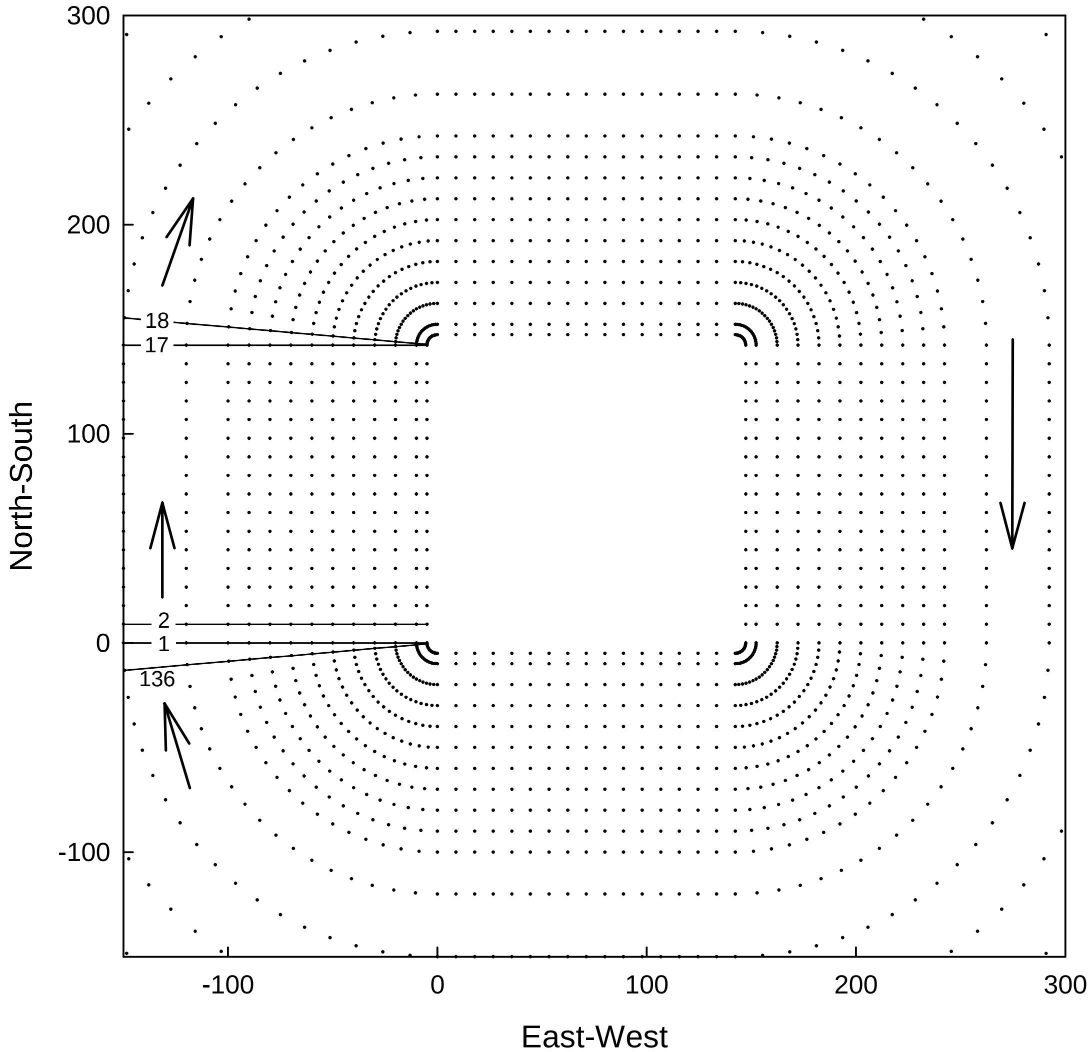


Figure 2. Spoke numbering scheme for 5 acre, square plot, fine grid. First spoke begins at southwest corner of field, extending due west. Subsequent spokes originate from the edge moving clockwise. There are 17 spokes along each straight edge and 17 spokes radiating from each corner, for a total of 136 spokes. Lines are drawn for illustration purposes for spokes 1,2,17,18 and 136.

Figure 3. Relationship between the methyl bromide 99% whole field buffer zone length (m) and the equivalent maximum direction buffer zone percentile. Equivalent maximum direction percentile = individual application level protection probability = (1 – individual application buffer zone failure rate).

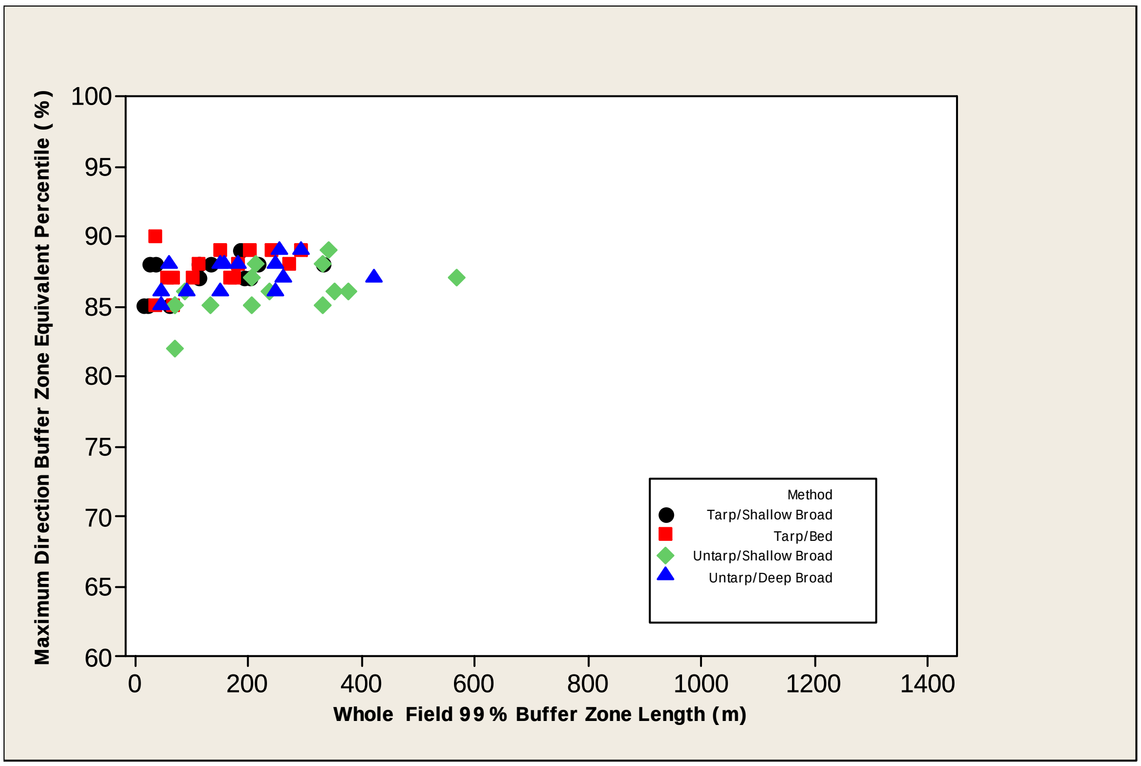


Figure 4. Relationship between the metam sodium 99% whole field buffer zone length (m) and the equivalent maximum direction buffer zone percentile. Equivalent maximum direction percentile = individual application level protection probability = (1 – individual application buffer zone failure rate).

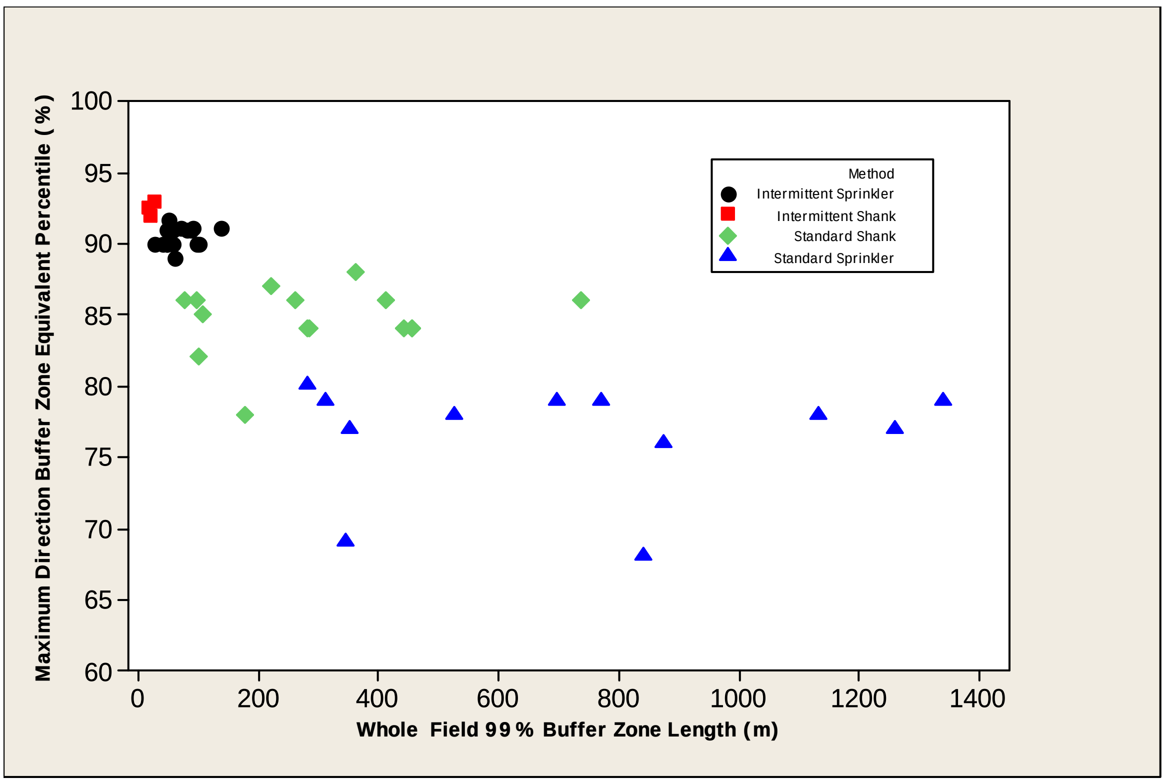


Figure 5. Relationship between the chloropicrin 99% whole field buffer zone length (m) and the equivalent maximum direction buffer zone percentile. Equivalent maximum direction percentile = individual application level protection probability = (1 – individual application buffer zone failure rate).

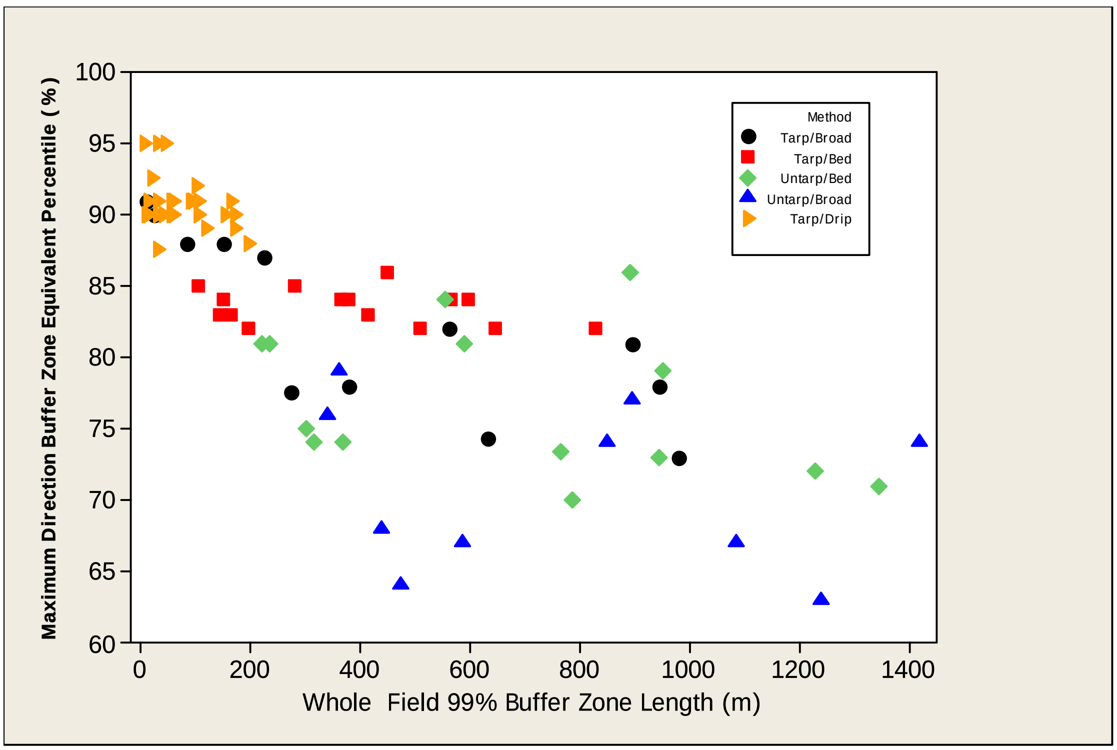
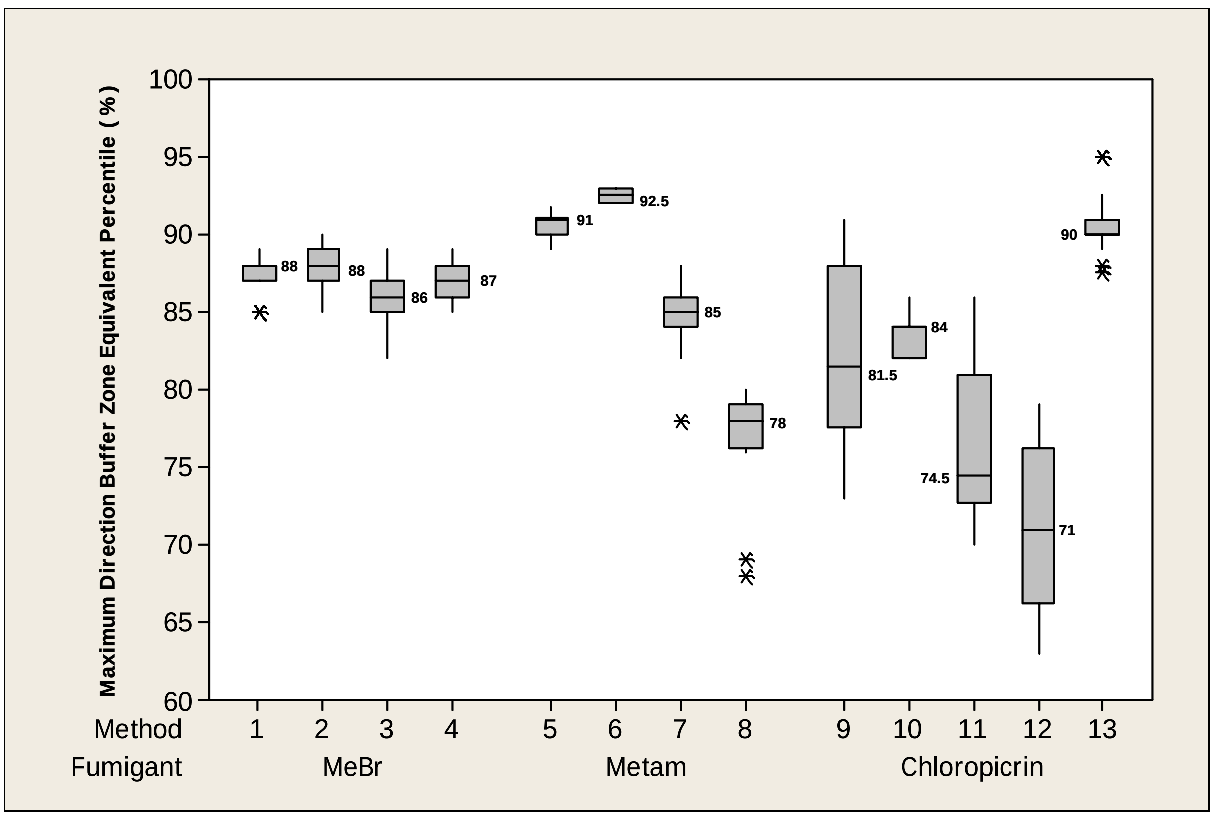


Figure 6. Summary of the maximum direction buffer zone equivalent percentiles for the 99% whole field buffer zone of application methods for methyl bromide, metam sodium and chloropicrin. The application methods within each fumigant are as follows: methyl bromide (MeBr) 1 = tarp/broadcast, 2 = tarp/bed, 3 = untarp/shallow, 4 = tarp/deep. Metam sodium (Metam) 5 = intermittent watering-in sprinkler, 6 = intermittent watering-in shank, 7 = standard shank, 8 = standard sprinkler. Chloropicrin (Chloropicrin) 9 = tarp/broadcast, 10 = tarp/bed, 11 = untarp/bed, 12 = untarp/broadcast, 13 = tarp/drip. Key to the boxplot: the median value is the line shown inside each box. The value of the median for each box is labeled next to the line. The top and both of the box indicate the lower and upper quartiles. The line (whisker) extends to the lower and upper values that are within 1.5 times the inter-quartile range. The stars indicate outlier values. Equivalent maximum direction percentile = individual application level protection probability = (1 – individual application buffer zone failure rate).



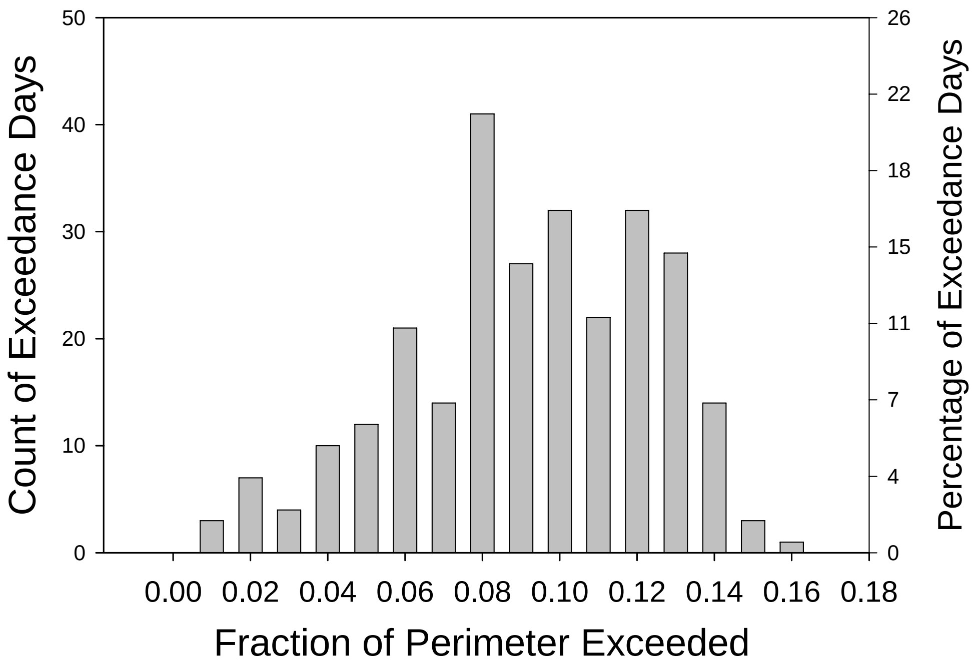


Figure 7. Fine grid, 5 acre scenario with histograms of the daily fractions of the perimeter where the concentration exceeded the reference level. The total days were 1794, of which 1523 days showed no exceedance. This figure plots the exceedances for the 271 days where 1 or more spokes showed an exceedance.

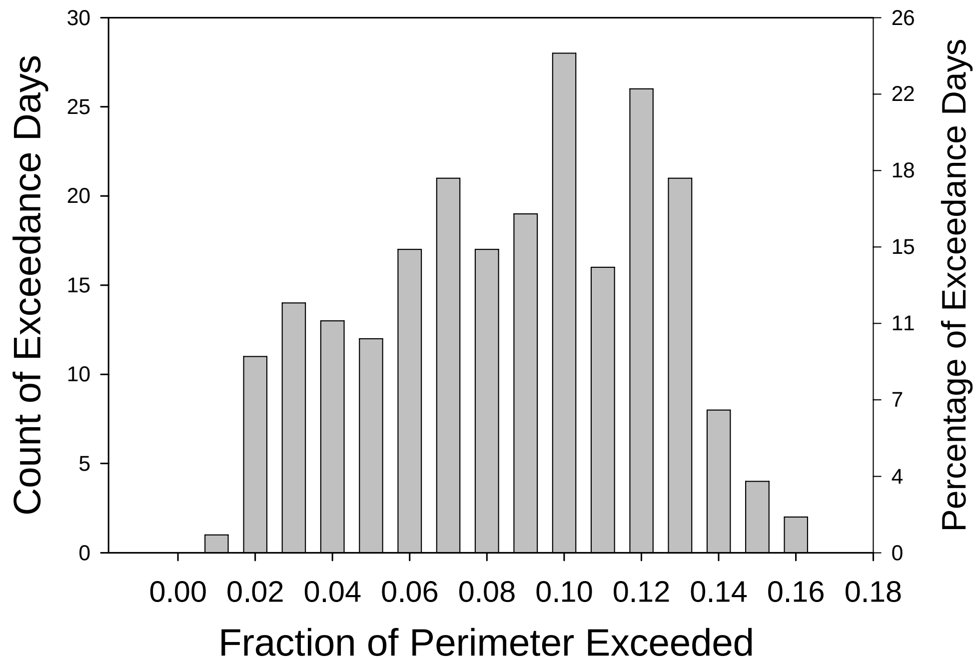


Figure 8. Fine grid, 20 acre scenario with histograms of the daily fractions of the perimeter where the concentration exceeded the reference level. The total days were 1794, of which 1564 days showed no exceedance. This figure plots the exceedances for the 230 days where 1 or more spokes showed an exceedance.

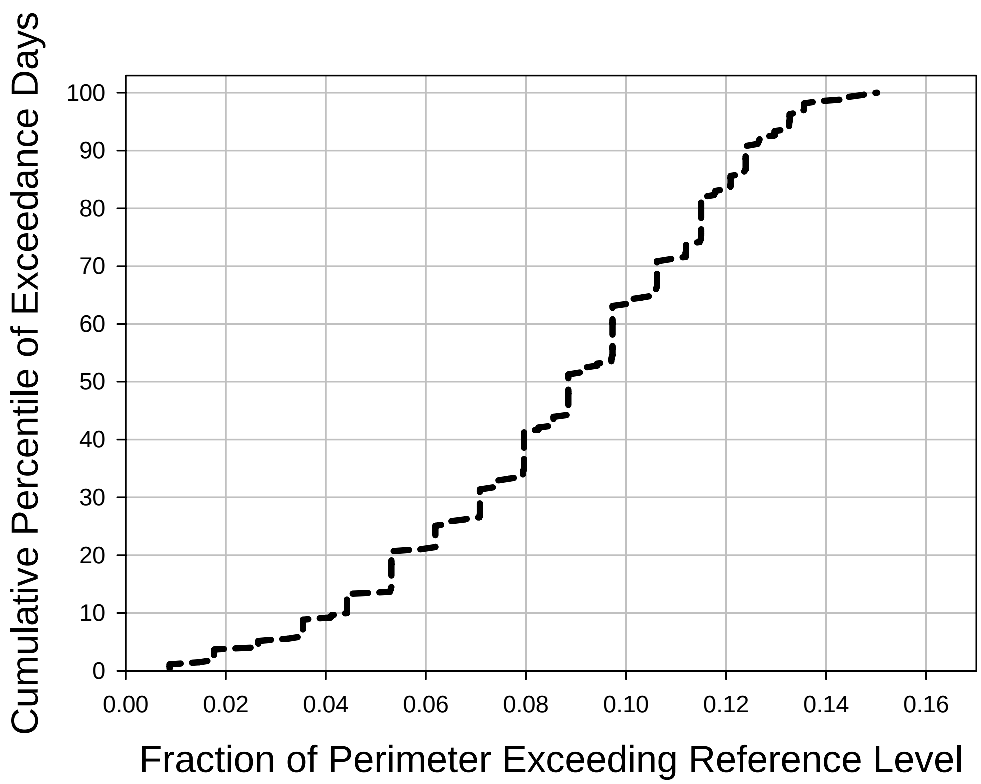


Figure 9. Cumulative distribution of perimeter length exceedances for 5 acre, fine grid scenario based on 271 days where at least one spoke exceeded the reference concentration at the buffer zone distance.

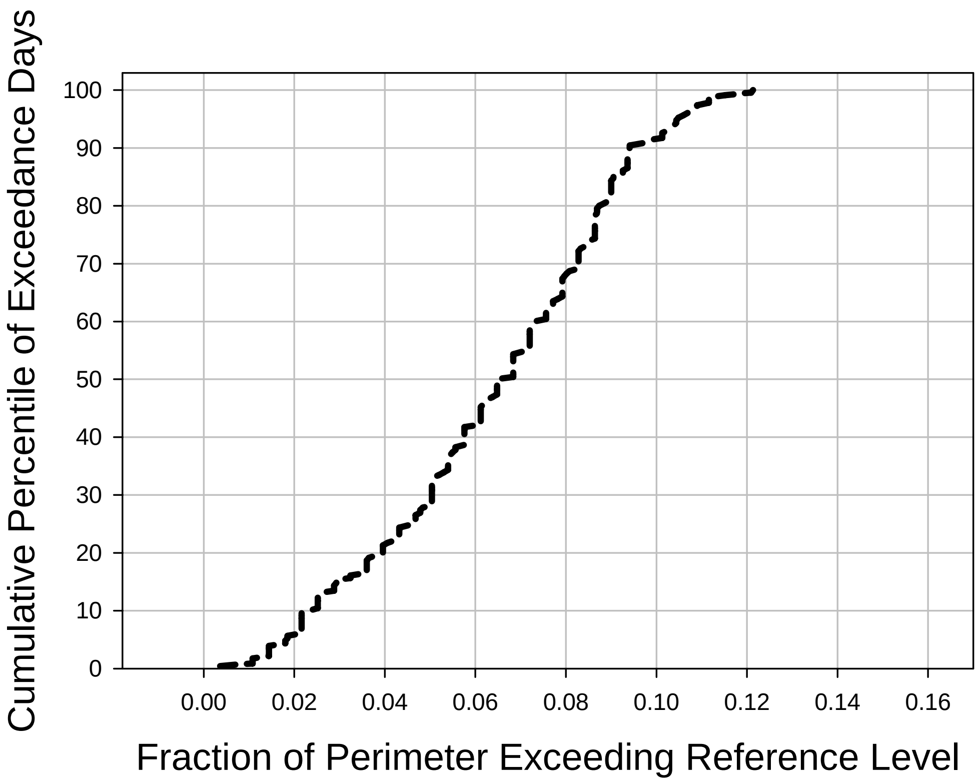


Figure 10. Cumulative distribution of perimeter length exceedances for 20 acre, fine grid scenario based on 230 days where at least one spoke exceeded the reference concentration at the buffer zone distance.

Appendix A. Control file used for 20 acre, fine grid, shallow, tarped methyl bromide application.

```
001  * PERFUM2 Input File
002  *** Specify scenario type ****
003  ** SF = single field
004  ** MF1 = multiple field no. 1 (4 fields surrounding main field
005  ** MF2 = multiple field no. 2 (large field broken into quadrants)
006  ** MOE = margin of exposure (for single fields only)
007  ** GRN = greenhouse scenario
008  Scenario Type:                SF
009  * ISCST3 Portion of Control File - Used for all scenarios
010  ISCST3 input file:            SF.inp
011  ISCST3 output file:           SF.out
012  Met station ID:               99999
013  Upper air station ID:         99999
014  Field length x-direction (m): 284.5
015  Field length y-direction (m): 284.5
016  Grid density (C/F):           F
017  ** Additional information for MF1 Scenario
018  Distance between sources (m): 450.0
019  Fluxes (enter or proportion): P
020  Flux proportion:              1.0
021  ** Additional information for MF2 Scenario
022  Main source:                  3
023  Flux choice (P/E):            P
024  Flux proportion for NE:       0.30
025  Flux proportion for NW:       0.15
026  Flux proportion for SW:       1.0
027  Flux proportion for SE:       0.05
028  ** Additional information for the Greenhouse scenario
029  Source type (P/A):            P
030  Building Height (meters):     15.0
031  Adjusted Height (meters):     15.0
032  Flux choice (C/E):            C
033  App rate (lbs/1000ft3):       3.0
034  Time spent applying (hours):  0.1
035  Time spent treating (hours):  4.0
036  AER (hr-1) treatment:         0.5
037  AER (hr-1) aeration:          2.0
038  Stack height, m (above bldg): 1.0
039  Stack diameter (m):           1.0
39A  Exit velocity (m/sec):        0.05
040  * Buffer zone model portion - general inputs for all scenarios
041  Flux data source:             CDPR Commodity Permit Conditions
042  Meterological source          Ventura, California
043  Number of simulation days:    2
044  Averaging Period:             24
045  Distribution Avg. Period:     24
046  Begin Year:                   1995
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```
End Year:                      1999
Starting Hour:                 10
Meteorological file:           vtx.MET
Output file:                   PERFUM.OUT
Plot file:                     PERFUM.PLT
Contour file:                  PERFUM.CTR
Contour Percentile:            95
NOEL or HEC (ug/m3):           38830.0
UF:                            30.0
Buffer length (m):             165.0
** Include application rates for calculation
Number of Application rates:  1
Application rate no. 1:        430.0
Application rate no. 2:
Application rate no. 3:
Application rate no. 4:
Application rate no. 5:
Application rate no. 6:
Application rate no. 7:
Application rate no. 8:
Application rate no. 9:
Application rate no. 10:
** Flux data for Main Source
Hour1:                         183.68 100.28
Hour2:                         183.2 97.04
Hour3:                         181.85 93.9
Hour4:                         179.79 90.86
Hour5:                         177.16 87.92
Hour6:                         174.0 85.08
Hour7:                         170.63 82.34
Hour8:                         166.92 79.68
Hour9:                         163.01 77.12
Hour10:                        0.2 158.95
Hour11:                        4.63 154.81
Hour12:                        18.54 150.6
Hour13:                        39.63 146.38
Hour14:                        63.52 142.16
Hour15:                        87.1 137.98
Hour16:                        108.61 133.83
Hour17:                        127.26 129.75
Hour18:                        142.83 125.75
Hour19:                        155.4 121.82
Hour20:                        165.21 117.99
Hour21:                        172.57 114.25
Hour22:                        177.8 110.6
Hour23:                        181.21 107.06
Hour24:                        183.09 103.62
** Flux data for Multiple Source No. 1
Hour1:
Hour2:
```

```
Hour3:
Hour4:
Hour5:
Hour6:
Hour7:
Hour8:
Hour9:
Hour10:
Hour11:
Hour12:
Hour13:
Hour14:
Hour15:
Hour16:
Hour17:
Hour18:
Hour19:
Hour20:
Hour21:
Hour22:
Hour23:
Hour24:
** Flux data for Multiple Source No. 2
Hour1:
Hour2:
Hour3:
Hour4:
Hour5:
Hour6:
Hour7:
Hour8:
Hour9:
Hour10:
Hour11:
Hour12:
Hour13:
Hour14:
Hour15:
Hour16:
Hour17:
Hour18:
Hour19:
Hour20:
Hour21:
Hour22:
Hour23:
Hour24:
** Flux data for Multiple Source No. 3
Hour1:
Hour2:
```

```
Hour3:
Hour4:
Hour5:
Hour6:
Hour7:
Hour8:
Hour9:
Hour10:
Hour11:
Hour12:
Hour13:
Hour14:
Hour15:
Hour16:
Hour17:
Hour18:
Hour19:
Hour20:
Hour21:
Hour22:
Hour23:
Hour24:
** Flux data for Multiple Source No. 4
Hour1:
Hour2:
Hour3:
Hour4:
Hour5:
Hour6:
Hour7:
Hour8:
Hour9:
Hour10:
Hour11:
Hour12:
Hour13:
Hour14:
Hour15:
Hour16:
Hour17:
Hour18:
Hour19:
Hour20:
Hour21:
Hour22:
Hour23:
Hour24:
```

Appendix B. Discussion of modification of PERFUM2 to obtain daily spoke-specific buffer information.

Two situations were studied: 5 acre with fine grid and 20 acres with fine grid. The application scenario was shallow, tarped methyl bromide application using the maximum application rate of 430 lbs/acre. The flux is shown in Figure 1. While two 24-hour periods were included in the flux profile, the analysis focused on the first 24-hour period, which was the highest flux period. A listing of the PERFUM2 input file for 20 acres is shown in Appendix A. Ventura meteorology was used, though one day was removed due to a string of 24 hours of calms.

The PERFUM2.FOR source code was modified to print out both daily concentrations ordered by spoke/ring and spoke-specific buffer information. PERFUM2 calls ISCST3 (which has been adapted to become a subroutine for PERFUM2) and collects the concentration estimates at each spoke/ring coordinate for a day. Then PERFUM2 proceeds spoke by spoke and estimates the distance along each spoke to reach the reference concentration. The modifications were exclusively in the subroutine “DAYCALC”, which is contained in the PERFUM2.FOR file. The modifications are shown in full in Appendix B. Briefly, code was inserted to open files and write out internal values. The code modifications did not change the logic or calculations of the program.

Thus these modifications in the subroutine DAYCALC provided output which enabled (1) verification of the individual concentrations averages generated by PERFUM2, (2) analysis of the number of spokes each day where the reference concentration was exceeded along that spoke at the buffer zone distance, and (3) verification of the 99% whole field buffer distance. For (1) a single day was chosen, an independent ISCST3 control file was created and the discrete receptor concentrations from the single-day independent run were compared to the corresponding concentrations from PERFUM2 as found in CONCEN.OUT. For (2) the 99% whole field buffer zone was compared to each spoke-specific buffer zone each day. The daily spoke exceedance information was used to estimate a daily fraction of the buffer perimeter where the reference concentration was exceeded. These daily lengths were compiled into a distribution. For (3) the individual spoke length ‘buffers’ (distance to reach the reference concentration) were aggregated into a distribution and distributional points were compared to the PERFUM2 distribution points.

A small FORTRAN utility was written to analyze the results in SPOKEBUF.OUT. A listing of this program, COUNTXC.FOR, is provided in Appendix C. This program takes as user input, the whole-field buffer zone at a given percentile, and uses it to determine on a daily basis, the number of spokes where the actual concentration at the buffer zone distance exceeded the reference concentration. This was determined by comparing the ‘spoke bufferzone’ (in the last column of Table B1) to the whole field buffer zone and counting up the number of spokes for each day where the spoke bufferzone was larger than the whole-field buffer zone. This resulted in a per day number ranging from 0 to a maximum possible NSPOKE, counting the number of spokes where the whole-field buffer zone would be smaller than the spoke-bufferzone, or

Table B1. Small excerpt from SPOKEBUF.OUT for fine grid, 5 acre simulation. Columns are Julian day, year, IAPP, IDAYS, IAVG, number of spokes per field (twice), spoke number, and spoke-buffer. The spoke-buffer is the distance determined along each spoke to reach the reference concentration.

2	95	1	1	1	136	136	1	5.00
2	95	1	1	1	136	136	2	5.00
2	95	1	1	1	136	136	3	5.00
2	95	1	1	1	136	136	4	5.00
2	95	1	1	1	136	136	5	5.00
2	95	1	1	1	136	136	6	5.00
2	95	1	1	1	136	136	7	5.00

equivalently, where the concentration at the whole-field buffer distance was greater than the reference concentration.

The use of .GT. ("greater than") versus .GE. ("greater than or equal to") was compared and found no differences in the 5 acre fine grid, but 1 extra exceedance spoke in the 20 acre fine grid. Thus the differences were negligible and results are reported using the "greater than" version.

At the beginning of COUNTXC the user enters a value for 'TRUBUF', which in this study was the whole-field buffer zone at the 99th percentile. This is the value used to compare to each of the spoke-buffers. For 5 acres the 99th percentile whole field buffer was 60m and for 20 acres it was 200m. COUNTXC outputs a file consisting of 1794 records, which is the number of valid days of meteorological data for the Ventura meteorological data set. The columns consist of several fields. The fields are the Julian day, two digit year, number of spokes in flux period 1 where the buffer-spoke distance exceeded the whole-field buffer distance and a similar number for period 2. The next field (P1EDG) gives a count of the number of "edge spokes" that exceeded TRUBUFF on that day during flux period 1. Following that is the number of corner spokes (P1COR) that exceeded the TRUBUFF on that day during flux period 1.

We calculated the fraction of the perimeter that exceeded the reference concentration with two methods: by a simple count of exceedance spokes divided by total spokes and by an edge/corner spoke perimeter calculation that adjusted for the different arc-length represented by the edge versus corner spokes.

The columns "FRAC BY COUNT" gives the spoke exceedance count divided by the total spoke number. In this case, Table B2, the 20 acre field fine grid utilized 200 spokes. So, for example, the second line is labeled as Julian day 3 for 1995. What this actually corresponds to is Ventura meteorology from 10:00 on January 2 through 9:00 on January 3 inclusive, since the application start hour was 10:00. This is labeled as Julian day 3. For this 24-hour meteorology period, 25 spokes saw an exceedance of the threshold at the buffer zone distance of 200m. All 25 spokes were from edge spokes. No corner spokes showed exceedances on this day. The fraction by simple counting was 0.125 (=25/200).

The second fraction, "FRAC BY LEN", shows the edge/corner perimeter calculation, which uses the arc-adjusted fraction of the perimeter. The total perimeter at the buffer zone distance, D, consists of the four sides, S, plus a circle with radius B (TRUBUFF, i.e. the 99% whole field buffer zone), which has a perimeter of $2\pi B$ and thus the entire perimeter is $D=4S+2\pi B$

In order to calculate the contribution from each edge spoke, it is necessary to determine the number of edge spokes. The general pattern of spokes is shown in Figure 2. For fine grids there are 17 spokes at each corner. This gives 18 divisions at the corner, which provides 5 degree separations between corner spokes. The file SPOKEBUF.OUT contains the total number of spokes for each field. By subtraction, the number of edge spokes can be determined. For the 20 acre fine grid, the total number of spokes was 200. The number of corner spokes was 68 (=4*17) and the number of edge spokes was 132. In order to get the perimeter contribution from each edge or each corner spoke, the corresponding perimeter is divided by the number of that kind of spoke. For edge spokes, CE=4S/#edge spokes and for corner spokes, CC=2πB/#corner spokes. For 20 acre fine grid, for example, CE=284.5*4/132=8.62m/spoke and for the corners, CC=2*3.14*200/68=18.47m/spoke.

Table B2. Small excerpt from COUNTXC.OUT, for the 20 acre, fine grid run, showing Julian day, year, number of spoke-buffers exceeding whole-field buffer zone distance for period 1 and period 2, count of edge spokes exceeding the buffer (i.e. when the reference concentration along a spoke occurred at a distance greater than the tested buffer zone), count of corner spokes exceeding the buffer, fraction of spokes exceeding the buffer and fraction of the perimeter exceeding the perimeter at the buffer distance from the field. The tested buffer was the 99th percentile whole-field buffer zone calculated by PERFUM.

```
THE TESTED BUFFER ZONE USED WAS     200.00
 THE STRAIGHT EDGES PERIMETER TOTAL         1138.00
 THE CIRCULAR PERIMETERS TOTAL              1256.64
 THE TOTAL PERIMETER AT THE BZ DIST         2394.64
 THE LENGTH PER EDGE SPOKE IS                8.6212
 THE LENGTH PER CORNER SPOKE IS             18.4799
 THE NUMBER OF CORNER SPOKES IS        68
 THE NUMBER OF EDGE SPOKES IS         132
 JULIAN DAY,YEAR,PERIOD 1 EXCEED COUNT, PERIOD 2 EXCEED COUNT
 PER 1 EDGE SPOKE CNT, PER 1 CORNER SPOKE CNT, PER 1 FRACTION BY CRUDE COUNT,
 PER 1 FRACTION BY PERIMETER LENGTH ADJST FOR CORN
```

JULDAY	YEAR	CNT1	CNT2	P1EDG	P1COR	FRAC BY COUNT	FRAC BY LEN
2	95	0	0	0	0	0.0000	0.0000
3	95	25	0	25	0	0.1250	0.0900
4	95	20	0	18	2	0.1000	0.0802
5	95	0	0	0	0	0.0000	0.0000
6	95	20	0	20	0	0.1000	0.0720
7	95	0	0	0	0	0.0000	0.0000
15	95	0	10	0	0	0.0000	0.0000
16	95	8	0	8	0	0.0400	0.0288
17	95	14	0	11	3	0.0700	0.0628
18	95	0	0	0	0	0.0000	0.0000
19	95	0	0	0	0	0.0000	0.0000
20	95	0	0	0	0	0.0000	0.0000

In line 3 of Table B2, there were 18 edge spokes and 2 corner spokes where the reference concentration was exceeded at the buffer zone distance. The simple count fraction was (=20/200). The corner/edge perimeter calculation fraction was 0.1 0.08 (=(17*8.62+2*18.47)/2394).

Finally, SORTSPOKE.FOR was written to process the output in the file, SPOKEBUF.OUT, by extracting the spoke-by-spoke distances to the reference concentration, sorting these distances and creating an output file called SORTSPOKE.OUT. The distance percentiles in SORTSPOKE.OUT corresponds to the whole-field cumulative distributions estimated by PERFUM2. Thus at for these two cases, the PERFUM2 whole-field buffer zone percentile calculation could be checked.

Appendix C. Modifications to the subroutine DAYCALC.

The DAYCALC code is shown below. The modifications made to this subroutine for our analysis are bolded and begin at line 1528 (line numbers not shown) of the PERFUM2 routine, DAYCALC, with a comment "BRJ070726 ADDED CODE HERE TO…".

```
C***************************************************************************************************

      SUBROUTINE DAYCALC

C***************************************************************************************************
C                 DAYCALC
C
C        PURPOSE: Calculate daily average concentrations at each receptor
C                 point.  Then an interpolation is performed for each
C                 spoke in the receptor grid, and a buffer length is
C                 calculated for each spoke.  Also, the daily maximum
C                 buffer length is calculated.  All of these calculations
C                 are additionally performed on a monthly basis for
C                 seasonal analysis.
C
C        INPUTS:  Daily totals of concentrations by receptor points
C
C        OUTPUTS: Daily average buffer lengths
C
C        CALLED FROM:  ISCST3 subroutine
C
C************************************************************************


       USE MAIN1
       USE BUFFER1

       IMPLICIT NONE

       INTEGER I,J,K,M


       NDAYS_PER = NDAYS_PER + 1

C      Start application rate loop
       DO 500 IAPP=1,NAPPRATES
C      Start flux day loop
       DO 500 IDAYS=1,NFLUXDAYS
C      Start avering time loop
       DO 500 IAVG=1,IAVG_PER

       IDIST_AVG = DIST_AVG(IAVG)

C      Calculate daily average concentration.  Use EPA's calms policy.  For a
C      24-hour period, divide daily concentration total by the maximum of the
C      non-calm hours, or 75% of the the number of hours (24)- +0.4 added per
C      ISCST3 code

      PER_HOURS = MAX(NON_CALM_HOURS(IAVG),NINT(AVG_TIME*0.75+0.4))
      IF(NON_CALM_HOURS(IAVG) .EQ. 0) THEN
        GOTO 500
      ENDIF
```

```
C      Divide by the number of non-calm hours to get the average concentration.
C      Adjust for the application rate.

C BRJ 070726 ADDED CODE HERE TO OUTPUT THE CONCENTRATIONS AND RING/SPOKE IDS
       OPEN(UNIT=27182,STATUS='UNKNOWN',POSITION='APPEND',
     1      FILE='CONCEN.OUT')  !CLOSE FILE AFTER 10 DO LOOP

       DO 10 I=1,NUMREC

         IRING = RINGID(I)
         ISPOKE = SPOKEID(I)

C        Averaging period calculation
         CONC_DISP_TMP(IRING,ISPOKE) =
     >     CONC_DISP(I,IDAYS,IAVG)/PER_HOURS


C        Adjustment for application rate
         CONC_DISP_TMP(IRING,ISPOKE) =
➢       CONC_DISP_TMP(IRING,ISPOKE)*(AppRate(IAPP)/AppRate(1))

C BRJ 070726 WRITE OUT THE DAY,YEAR, RING ID AND SPOKE ID AND CONCENTRATION
         WRITE(27182,37182)LJDAY,LYEAR,IDAYS,I,IRING,ISPOKE,
     1         CONC_DISP_TMP(IRING,ISPOKE)
37182    FORMAT(1X,6I6,F15.2)

10     CONTINUE
       CLOSE(27182)

        BUFFER_MAX = 0.                 ! initialize maximum buffer zone variable to zero

C BRJ 070724 OPEN FILE FOR APPENDING, INTERPOLATE SUBROUTINE PRODUCES 'BUFFER', WHICH IS
C BUFFER ALONG THAT SPOKE, FOR EACH SPOKE, SO WILL PRINTOUT NUMBER OF SPOKES PER FIELD, SPOKE
C NUMBER AND BUFFER, ARE ASSUMING 24 HOUR EXPOSURES
        OPEN(UNIT=31415,STATUS='UNKNOWN',POSITION='APPEND',
     1       FILE='SPOKEBUF.OUT')  !CLOSE THE FILE AFTER 110 DO LOOP BELOW
C
C       Begin to loop over each spoke
        DO 110 ISPOKE=1,NSPOKE_PER_FIELD

C         Call the interpolation subroutine to estimate the buffer distance for this spoke

          CALL INTERPOLATE(ISPOKE)

C BRJ 070724 INSERT THE PRINT STATEMENT TO GET THE TIME AND OTHER RELEVENAT INFO FOR THIS BUFFER

          WRITE(31415,61415)LJDAY,LYEAR,IAPP,IDAYS,IAVG,
     1                           NSPOKE_PER_FIELD
     2                             ,NSPOKE_PER_FIELD,ISPOKE,BUFFER
61415     FORMAT(1X,8I5,F10.2)


C         Update the buffer zone frequency arrays.  These arrays store the
C         frequency by which each buffer distance was found.
C         For the whole field calculation, the BUFFER_FREQ array is used
C         For the whole field monthly calculation, the BUFFER_FREQ_MON
C         array is used.  The first array indices refer to specific buffer
C         distances between 0 and 300, at *5 meters for each indice


          IASSIGN = 0                   ! Variable to check if a frequency was assigned
```

```
(……section of code omitted…….)

110     CONTINUE
C BRJ 070724 CLOSE THE SPECIAL OUTPUT FILE
        CLOSE(UNIT=31415)
```

The first modification opens a new file "CONCEN.OUT", which receives the daily average concentrations by spoke. This file was used to directly compare independently run ISCST3 calculations for a selected day to verify the PERFUM2 calculations.

A few lines later a file called "SPOKEBUF.OUT" is opened for output. A few lines down, within the 110 Do Loop, the original code calls a subroutine, INTERPOLATE(ISPOKE). This subroutine computes the distance out along the particular spoke identified by the index, ISPOKE, until the reference concentration is reached. The value is returned in variable called BUFFER, which is not shown in this portion of the code. The second modification consists of a couple of lines which write out to the file, SPOKEBUF.OUT, the current values for several variables. The important variables are LJDAY, LYEAR, IDAYS, ISPOKE and BUFFER. LJDAY is the Julian day of the year. LYEAR is the last 2 digits of the calendar year (95, for example). IDAYS is the period number. In this case, there were two 24-hour flux periods and so IDAYS took on a value of either 1 or 2. ISPOKE is the spoke number, which in this case ranged from 1 to 40 for the 5 acre field. The control file was set up to only use one application rate, so that IAPP was always 1. Similarly, IAVG was equal to 1, as the number of averaging periods per 24 hour day. The final modification occurred just after the end of the 110 DO LOOP and closed the output unit.

Thus, these modifications to the PERFUM2 source code created two new files, CONCEN.OUT and SPOKEBUF.OUT, which respectively record the concentration calculations and list day by day, the distances along each spoke to reach the reference concentration. A single day of output consisted of 2*NSPOKE records (for five acres coarse grid, NSPOKE=40, 5 acres fine grid NSPOKE=136 and for 20 acres fine grid, NSPOKE=200) because there were two 24-hour flux periods in this example. Table 1 shows a small excerpt from SPOKEBUF.OUT for a 5 acre, coarse grid. The last column in Table B1, spoke buffer, gives the estimated distance along that particular spoke on that particular day to reach the reference concentration.

Appendix D. Listing of program COUNTXC.FOR.

```
C     Last change:  BRJ  30 Jul 2007    4:15 pm
        PROGRAM COUNTXC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C 070730 MODIFIED COUNTXB (WHICH WAS FOR 5 ACRES) TO COUNTXC, WHICH WILL BE
C FOR 20 ACRES. 20 ACRES, ACCORDING TO THE CONCEN.OUT (WHICH IS NOW ZIPPED
SINCE
C IT'S OVER 1GB) THERE ARE 200 SPOKES FOR THE 20 ACRE FIELD.  AND WITH THE
NORMAL CONFIGURATION OF 17 SPOKES
C AT EACH CORNER (TO GIVE THE 5 DEGREES OF SEPARATION, HAH, CLOSE THAN 6)
C SO, 200-4*17=132 AND 132/4 = 33 SPOKES PER EDGE.  AND THE EDGE LENGTH IS
284.5M
C SO THAT 284.5/32=8.89M, WHICH MATCHES THE DISCRETE RECEPTOR FILE, WHERE
C THE PROGRESSIVE INCREMENT BETWEEN SPOKES ALONG THE EDGE IS 8.89
(BUFSPOKE.OUT)
C
C
C 070727 COUNTXB USES COUNTXA, AND ADDS SEVERAL MORE COLUMNS.  TWO COLLUMNS
C WILL BE FOR COMPUTING THE FRACTION OF THE PERIMETER THAT IS EXCEEDED,
C USING EQUAL WEIGHTS FOR EACH SPOKE (136 SPOKES FOR FINE GRID FOR 5 ACRES)
C THE NEXT FOUR COLUMNS (2 FOR EACH PERIOD) WILL USE THE ACTUAL PERIMETER
C CALCULATIONS, THSU FOR THE STRAIGHT SIDES (WEST, NORTH, EAST, SOUTH) EACH
C SPOKE IS WORTH (4*142.3)/68=8.37M AND FOR THE CORNERS, EACH SPOKE IS WORTH
C (2*PI*B)/68, WHICH FOR 60M IS 5.54M, AND THE TOTAL PERIMETER IS 519.29 FOR
TRUBUF=60
C
C 070726 COUNTXA MODIFIED TO USE PARAMETER NSPOKE IN PLACE OF 40 TO GET
FLEXIBILITY
C ON THE NUMBER OF SPOKES, SINCE IT APPEARS WE USED COARSE GRID FOR FIRST GO
ROUND
C INSTEAD OF FINE GRID, WHICH HAS INSTEAD OF 40 SPOKES, (15+17)*4=128 SPOKES,
VOILA!
c ACTUALLY, BASED ON THE OUTPUT FROM PERFUM2BJ (WHICH PRINTS OUT NSPOKE), THE
NUMBER
C OF SPOKES FOR THE FINE GRID 5 ACRE PLOT IS 136, I THINK THAT THE 15+17
FIGURE COMES
C FROM THE FIXED ISCST3 TEMPLATE CONTROL FILES THAT REISS HAD AVAILABLE FROM A
PREVIOUS
C VERSION, NOW THE CONTROL FILES ARE BUILT ON THE FLY
C
C 070725 I TRIED USING GE AND GT, GAVE SAME RESULTS IN FIRST EXAMPLE
C
C
C PROGRAM COUNTX, USES AS INPUT A SPECIAL OUTPUT FILE FROM
C PERFUM2 WHICH CONTAINS DAY, YEAR, SPOKE BUFFER
C AND ALSO USER INPUT FOR THE 'BUFFER' HOWEVER DETERMINED
C THEN COUNTX RUNS THROUGH THE FILE AND CALCULATES FOR EACH 24 HOUR PERIOD
```

```
C WHAT FRACTION OF THE PERIMETER EXCEEDED THE THRESHOLD, AND
C OUTPUTS THAT NUMBER FOR SUMMARY INTO A FREQUENCY DISTRIBUTION
C-------FOLLOWING IS OUTPUT LINE IN PERFUM2BJ---------------
C
C          WRITE(31415,61415)LJDAY,LYEAR,IAPP,IDAYS,IAVG,
C     1                             NSPOKE_PER_FIELD
C     2                                  ,NSPOKE_PER_FIELD,ISPOKE,BUFFER
C61415     FORMAT(1X,8I5,F10.2)
C------------------------------------------------------------
C LJDAY IS JULIAN DAY OF YEAR
C LYEAR IS 2 DIGITS OF YEAR
C IAPP IS COUNTER FOR THE APPLICATION RATE (SHOULD ALWAYS BE 1 IN THIS
EXAMPLE)
C IDAYS IS THE NUMBER OF FLUX DAYS (IS 1 OR 2 IN THIS EXAMPLE, SINCE 2 X 24
HOUR FLUX PERIODS)
C       I WILL ONLY BE USING THE FIRST 24 HOUR FLUX PERIOD
C IAVG IS A COUNTER FROM 1 TO IAVG_PER, THE LATTER IS THE NUMBER OF AVERGING
PERIODS PER DAY
C NSPOKE_PER_FIELD IS THE NUMBER OF SPOKES PER FIELD (40 FOR COARS GRID 5
ACRES, 136FOR FINE)
C ISPOKE IS THE SPOKE NUMBER
C BUFER IS A REAL NUMBER, THE DISTANCE AT WHCIH THE THRESHOLD CONCENTRATION IS
REACHED
C  LJDAY LYEAR IAPP IDAYS IAVG NS_P_F ISPOKE BUFFER
C1234567890123456789012345678901234567890123456789012345678901
C     2   95    1    1    1   40   40    1      5.00
C     2   95    1    1    1   40   40    2      5.00
C     2   95    1    1    1   40   40    3      5.00
C     2   95    1    1    1   40   40    4      5.00
C     2   95    1    1    1   40   40    5      0.00
C     2   95    1    1    1   40   40    6      0.00
C     2   95    1    1    1   40   40    7      0.00
C     2   95    1    1    1   40   40    1      5.00
C     2   95    1    1    1   40   40    2      5.00
C     2   95    1    1    1   40   40    3      5.00
C     2   95    1    1    1   40   40    4      5.00
C     2   95    1    1    1   40   40    5      0.00
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        IMPLICIT NONE
        INTEGER NSPOKE
        REAL SIDE !SIDE OF SQUARE FIELD
        REAL PI  !THE CONSTANT
C        PARAMETER (NSPOKE=136)  5 ACRES
C        PARAMETER (SIDE=142.3) !FOR 5 ACRES SIDE IS 142.3M
        PARAMETER (NSPOKE=200) !200 SPOKES FOR 20 ACRES, STILL 17 PER CORNER
        PARAMETER (SIDE=284.5) !FOR 20 ACRES SIDE IS 284.5M
        PARAMETER (PI=3.14159) !AHHHH, PI WONT CHANGE WITH ACREAGE
        INTEGER LJDAY(NSPOKE,2),LYEAR(NSPOKE,2),SPOKE(NSPOKE,2)
        REAL BUFF(NSPOKE,2),TRUBUF
```

```
        INTEGER COUNTDAYS, I,J,K, COUNT1,COUNT2,COUNTREC
        INTEGER IAPP(NSPOKE,2),IDAYS(NSPOKE,2),IAVG(NSPOKE,2)
        INTEGER NS_P_F(NSPOKE,2)
        INTEGER ISPOKE(NSPOKE,2)
        REAL PERIMETER, EDGELEN, EDGEPERSPOKE,ARCPERSPOKE, ARCLEN
        INTEGER EDGECNT,CORNCNT,KI
        REAL FRACPERI,FRACCNT
        INTEGER CORNSPOKE,EDGESPOKE !CALCULATED NUMBER OF CORNER SPOKES VS
EDGE SPOKES
        INTEGER EC20 !FUNCTION DETERMINES IF EDGE (=1) OR CORNER (=0) FOR 20
ACRES
        !PERIMETER IS TOTAL PERIMETER LENGTH AT A BUFFER ZONE DISTANCE
        ! EDGELEN IS LENGTH OF FIELD PERIMETER (SUM OF 4 SIDES)
        !EDGEPERSPOKE IS LINEAR DISTANCE EACH EDGE SPOKE REPRESENTS
        !ARCPERSPOKE IS ARC DISTANCE EACH CORNER SPOKE REPRESENTS
        !ARCLEN IS PERIMETER OF CIRCLE WITH BUFFER ZONE AS RADIUS
        OPEN(UNIT=1,STATUS='OLD',FILE='SPOKEBUF.OUT')
        OPEN(UNIT=2,STATUS='UNKNOWN',FILE='COUNTXC.OUT')
        WRITE(6,100)
100     FORMAT(1X,'ENTER THE REAL NUMBER FOR THE BUFFER ZONE ')
        READ (5,*)TRUBUF
        WRITE(6,110)TRUBUF
110     FORMAT(1X,'THE BUFFER DIST YOU ENTERED WAS ',F12.3,
     1         /1X,' ')
        WRITE(2,95)TRUBUF
95      FORMAT(1X,'THE TESTED BUFFER ZONE USED WAS ',F10.2)
        EDGELEN=4.*SIDE  !FIELD PERIMETER
        ARCLEN=TRUBUF*2.*PI
        PERIMETER=EDGELEN+ARCLEN  !PI TIMES D IS CIRCUMFERENCE, REMEMBER?
        CORNSPOKE=4*17  !REISS ALWYAS USES 17 SPOKES ON CORNERS (18 DIVISIONS
GIVES 5 DEGREE SEPARATION)
        EDGESPOKE=NSPOKE-CORNSPOKE !TOTAL NUMBER OF EDGE SPOKES ARE WHAT IS
LEFT OVER
        EDGEPERSPOKE=EDGELEN/FLOAT(EDGESPOKE)    !AMT OF STRAIGHT EDGE PER N E
S W SPOKE
        ARCPERSPOKE=ARCLEN/FLOAT(CORNSPOKE) !AMT OF ARC DIST PER NW, NE, SE,
SW SPOKE FROM CORNER

        WRITE (2,97) EDGELEN,ARCLEN,PERIMETER,EDGEPERSPOKE,ARCPERSPOKE,
     1               CORNSPOKE, EDGESPOKE
97      FORMAT(1X,'THE STRAIGHT EDGES PERIMETER TOTAL ',F15.2,
     1        /1X,'THE CIRCULAR PERIMETERS TOTAL      ',F15.2,
     2        /1X,'THE TOTAL PERIMETER AT THE BZ DIST ',F15.2,
     3        /1X,'THE LENGTH PER EDGE SPOKE IS       ',F15.4
     4        /1X,'THE LENGTH PER CORNER SPOKE IS     ',F15.4,
     5        /1x,'THE NUMBER OF CORNER SPOKES IS     ',I5,
     6        /1X,'THE NUMBER OF EDGE SPOKES IS       ',I5)
        WRITE(2,107)
107     FORMAT(1X,'JULIAN DAY,YEAR,PERIOD 1 EXCEED COUNT, ',
     1            'PERIOD 2 EXCEED COUNT',
```

```
     2        /1X,'PER 1 EDGE SPOKE CNT, PER 1 CORNER SPOKE CNT, '
     3           , 'PER 1 FRACTION BY CRUDE COUNT, '
     4        /1X,'PER 1 FRACTION BY PERIMETER LENGTH ADJST FOR CORN')

C             WRITE(2,350)LJDAY(1,1),LYEAR(1,1),COUNT1,COUNT2,EDGCNT,CORNCNT,
C     1              FRACCNT,FRACPERI
C350     FORMAT(1X,6I8,2F12.4)
        WRITE(2,101)
101     FORMAT(7X,'JULDAY',' YEAR ','  CNT1 ','   CNT2 ', '   P1EDG ',
     1            '  P1COR '
     1            'FRAC BY COUNT ','FRAC BY LEN ')
        COUNTDAYS=0
        COUNT1=0
        COUNT2=0
        COUNTREC=0
C THERE ARE NSPOKE SPOKES PER FIELD, SO USE THAT TO STRUCTURE CALCULATIONS

1       CONTINUE  !BIG READ LOOP STARTS HERE

         DO I=1,NSPOKE      !THIS SHOULD BE WITH IDAYS=1
          READ(1,170,END=1000)LJDAY(I,1),LYEAR(I,1),IAPP(I,1),IDAYS(I,1)
     1                        ,IAVG(I,1),NS_P_F(I,1),SPOKE(I,1),
     2                         BUFF(I,1)
         END DO

         DO I=1,NSPOKE      !THIS SHOLD BE WITH IDAYS=2
          READ(1,170,END=1000)LJDAY(I,2),LYEAR(I,2),IAPP(I,2),IDAYS(I,2)
     1                       ,IAVG(I,2),NS_P_F(I,2),SPOKE(I,2),BUFF(I,2)
170       FORMAT(1X,6I5,5X,I5,F10.2)
         END DO
         COUNTDAYS=COUNTDAYS+1
C DO SOME CHECKING
         DO I=1,NSPOKE
          IF((I.NE.SPOKE(I,1)).OR.(I.NE.SPOKE(I,2)).OR.(IDAYS(I,1).NE.1)
     1                       .OR.(IDAYS(I,2).NE.2).OR.(IAPP(I,1).NE.1).
     2                       OR.(IAPP(I,2).NE.1).OR.
     3                        (NS_P_F(I,1).NE.NSPOKE).
     4                       OR.(NS_P_F(I,2).NE.NSPOKE).OR.
     5                       (LJDAY(1,1).NE.LJDAY(MIN(NSPOKE,I+1),2))
     6                            .OR.
     7                       (LYEAR(1,1).NE.LYEAR(MIN(NSPOKE,I+1),2)))
     8                          THEN
C NOTE LAST PART OF PRECEEDING DOESN'T CHECK EVERYTHING BUT IF FIRST VALUE OF
C DAY AND YEAR EQUAL CORRESPONDING VALUES FOR THE NSPOKE RECORDS IN THE SECOND
HALF
C THEN I ASSUME THAT LYEAR, LJDAY VALUES FOR FIRST HALF ARE ALSO CONSTANT
             WRITE(6,203)
203          FORMAT(1X,'INDEXING ERROR..CHECK FOLLOWING DAY (1ST HALF ',
     1                 'SHOWN ')
             DO J=1,NSPOKE
```

```
              WRITE(6,205)LJDAY(J,1),LYEAR(J,1),IAPP(J,1),IDAYS(J,1),
     1                    IAVG(J,1),NS_P_F(J,1),SPOKE(J,1),BUFF(J,1)
205           FORMAT(1X,7I5,F10.2)
             END DO
             STOP
           ENDIF
         END DO

C DO SOME PROCESSING - SIMPLE CRUDE APPROACH, COUNT UP THOSE BUFFERS GREATER
THAN TRUBUF
C AND SOME ADDED PROCESSING FOR COUNTXB, USE THE ACTUAL PERIMETER CALCULATIONS
C ALSO COUNT THE INSTANCES OF EDGE VS CORNER SPOKE EXCEEDANCES, BASICALLY
FIRST
C 17 SPOKES ARE WEST, 2ND 17 ARE NW, 3 RD ARE NORTH, AND SO ON
C WILL DO THE EXTENDED CALCULATIONS ONLY FOR THE FIRST PERIOD
        COUNT1=0
        COUNT2=0
        EDGECNT=0
        CORNCNT=0
        DO I=1,NSPOKE
         IF(BUFF(I,1).GT.TRUBUF)THEN
C           KI=INT((I-1)/17)+1  !THIS FANCY-PANTS BIT WONT WORK FOR 20 ACRES,
USE FUNCTION EC20
            KI=EC20(I)  !GIVES VALUE OF 1 IF EDGE, VALUE OF 0 IF CORNER
           IF(MOD(KI,2).EQ.1)THEN
            EDGECNT=EDGECNT+1
           ELSEIF(MOD(KI,2).EQ.0)THEN
            CORNCNT=CORNCNT+1
           ENDIF
           COUNT1=COUNT1+1
         ENDIF
         IF(BUFF(I,2).GT.TRUBUF)COUNT2=COUNT2+1
        END DO
C HAVE TABULATED EXCEEDANCES FOR THIS DAY, NOW CALCULATE PERIMETERS AND
FRACTIONS
 !PERIMETER IS TOTAL PERIMETER LENGTH AT A BUFFER ZONE DISTANCE
        ! EDGELEN IS LENGTH OF FIELD PERIMETER (SUM OF 4 SIDES)
        !EDGEPERSPOKE IS LINEAR DISTANCE EACH EDGE SPOKE REPRESENTS
        !ARCPERSPOKE IS ARC DISTANCE EACH CORNER SPOKE REPRESENTS
        !ARCLEN IS PERIMETER OF CIRCLE WITH BUFFER ZONE AS RADIUS
        FRACPERI=FLOAT(EDGECNT)*EDGEPERSPOKE+FLOAT(CORNCNT)*ARCPERSPOKE !THE
WHOLE EXCEEDANCE LENGTH
        FRACPERI=FRACPERI/PERIMETER
        FRACCNT=FLOAT(COUNT1)/FLOAT(NSPOKE)
C RECORD THIS DAY OF RESULTS
        WRITE(2,350)LJDAY(1,1),LYEAR(1,1),COUNT1,COUNT2,EDGECNT,CORNCNT,
     1            FRACCNT,FRACPERI
350     FORMAT(1X,6I8,2F12.4)
        COUNTREC=COUNTREC+1
        GOTO1
```

```
1000    CONTINUE  !REACHED END OF FILE
        WRITE(6,1100)COUNTDAYS,COUNTREC
1100    FORMAT(1X,I10,' DAYS PROCESSED ',I10,' RECORDS WRITTEN')
        END PROGRAM

        INTEGER FUNCTION EC20(I)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C THIS FUNCTION RETURNS 1 IF I IS AN EDGE SPOKE AND 0 IF I IS A CORNER SPOKE
FOR 20 ACRES
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        IMPLICIT NONE
        INTEGER I,K
C 1-33 WEST EDGE                          1
C 34-50 NW CORNER                         0
C 51-83 NORTH EDGE                        1
C 84-100 NE CORNER                        0
C 101-133 EAST EDGE                       1
C 134-150 SE CORNER (MY LEAST FAVORITE)   0
C 151-183 S EDGE                          1
C 184-200 SW CORNER (MY MOST FAVORITE)    0
        IF(I.LT.1.OR.I.GT.200)GOTO10
        K=MOD(I-1,50) !MAPS 1-200 INTO 0-49
        IF(0.LE.K.AND.K.LE.32)THEN
          EC20=1                    !WE GOT A SIDE
          RETURN
        ELSEIF(33.LE.K.AND.K.LE.49)THEN
          EC20=0                    !WE GOT A CORNER
          RETURN
        ENDIF
10        WRITE(6,100)I
100     FORMAT(1X,'ERROR IN EC20 WITH I= ',I10)
        STOP
        END
```

Appendix E. Comparison of two methods for estimating the fraction of the perimeter where the threshold concentration was exceeded.

Amongst the days where exceedances occurred, Figures E1 and E2 provide distributions for the fraction of the buffer zone perimeter based on the arc-length method which exceeded the reference concentration. The two methods for calculating the fraction yielded somewhat different histograms, but the general limits and shapes were similar. In both cases the fractions ranged from 0.01 to about 0.15. In part, the differences between the 2 methods resulted from the different number of edge versus corner spokes between 5 acre and 20 acres fields and the relatively different arc lengths represented by the 5 acre and 20 acre cases.

For the 5 acre field, there were a total of 2447 edge spokes and 335 corner spokes where exceedances occurred. For the 20 acre field, edge spokes were also dominated where exceedances occurred with 3337 and 217 edge and corner spoke exceedances, respectively. A quick check against the 99th percentile whole field buffer, which was used to calculate these exceedances, provides satisfactory agreement. That is, for five acres, (2447+335)/(1794*136) is about 1%, as is, for twenty acres, (3337+217)/(1794*200). There were 136 and 200 spokes for the 5 and 20 acre field fine grid simulations.

The histograms in Figures E1 and E2 provide some indication of the distribution of fractions of perimeters which are exceeded, when there is an exceedance somewhere along the buffer zone perimeter. Figures E3 and E4 provide the same data expressed as cumulative distributions of perimeter exceedance fractions and can be utilized more quantitatively to calculate probabilities. Figures E3 and E4 depict the contrast between the 5 acre and 20 acre fields where the 2 methods provide comparatively reversed results. That is, for 5 acres, the corner/edge perimeter method gives higher perimeter fractions for 5 acres, but lower perimeter fractions for 20 acres. This reversal is caused by the difference in effect of the 99% whole field buffer, which for the 5 acre case results in an average arc length per corner spoke which was less than the arc length for the edge spoke (5.5m versus 8.4m), but in the 20 acre case, was larger than the edge spoke (18.5m versus 8.6m). This, in combination with the general prevalence of exceedances along the edge spokes instead of the corner spokes, accounts for the differences between the two methods for calculating the daily perimeter exceedance fraction.

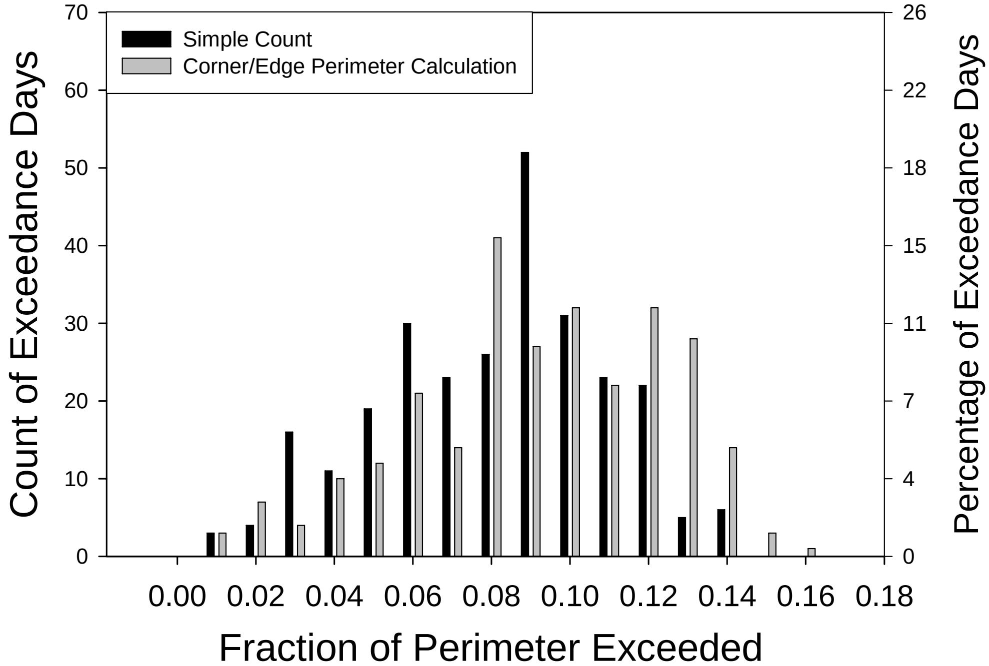

Figure E1. Fine grid, 5 acre scenario with histograms of the daily fractions of the perimeter where the concentration exceeds the reference level. The total days were 1794, of which 1523 days showed no exceedance. This figure plots the exceedances for the 271 days where 1 or more spokes showed an exceedance.

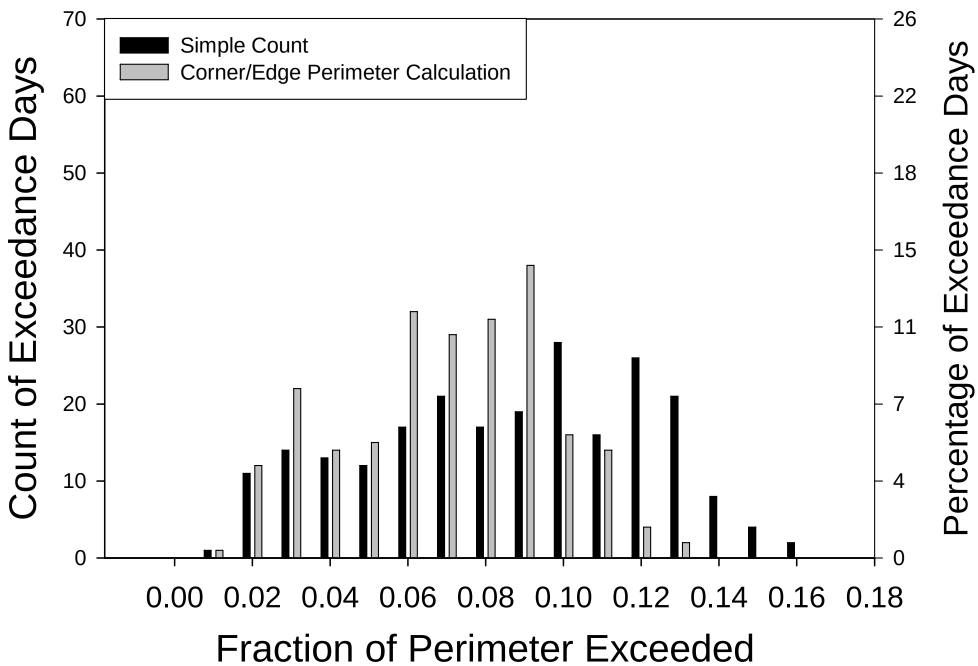

Figure E2. Fine grid, 20 acre scenario with histograms of the daily fractions of the perimeter where the concentration exceeds the reference level. The total days were 1794, of which 1564 days showed no exceedance. This figure plots the exceedances for the 230 days where 1 or more spokes showed an exceedance.

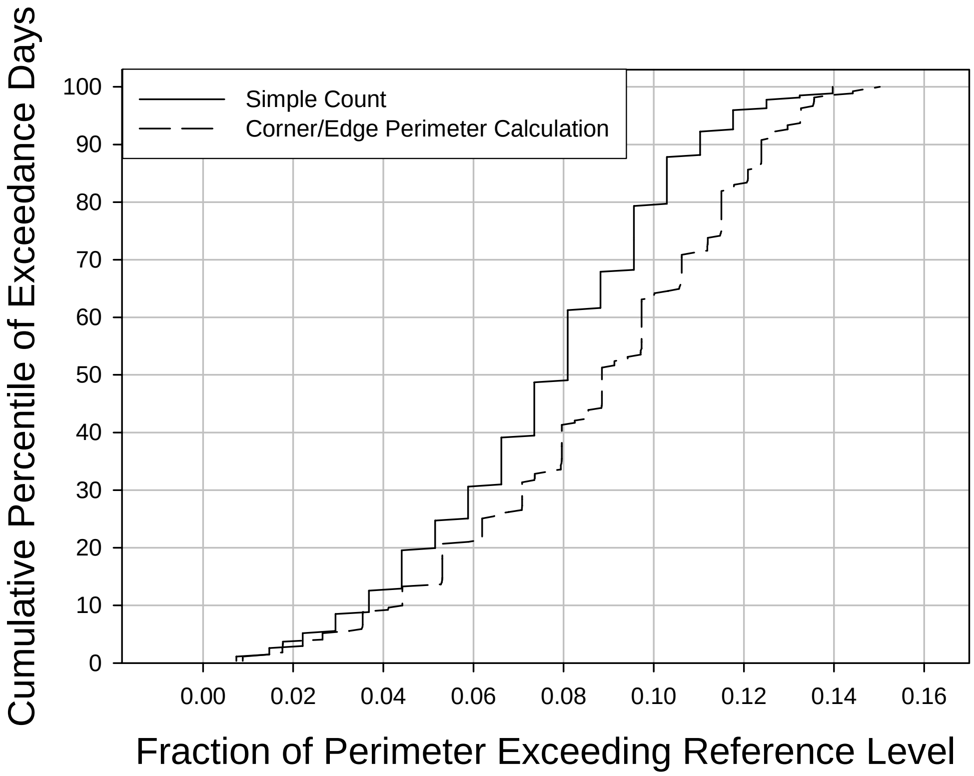

Figure E3. Cumulative distribution of perimeter length exceedances for 5 acre, fine grid scenario where 271 days showed at least one spoke exceeded the reference concentration at the buffer zone distance.

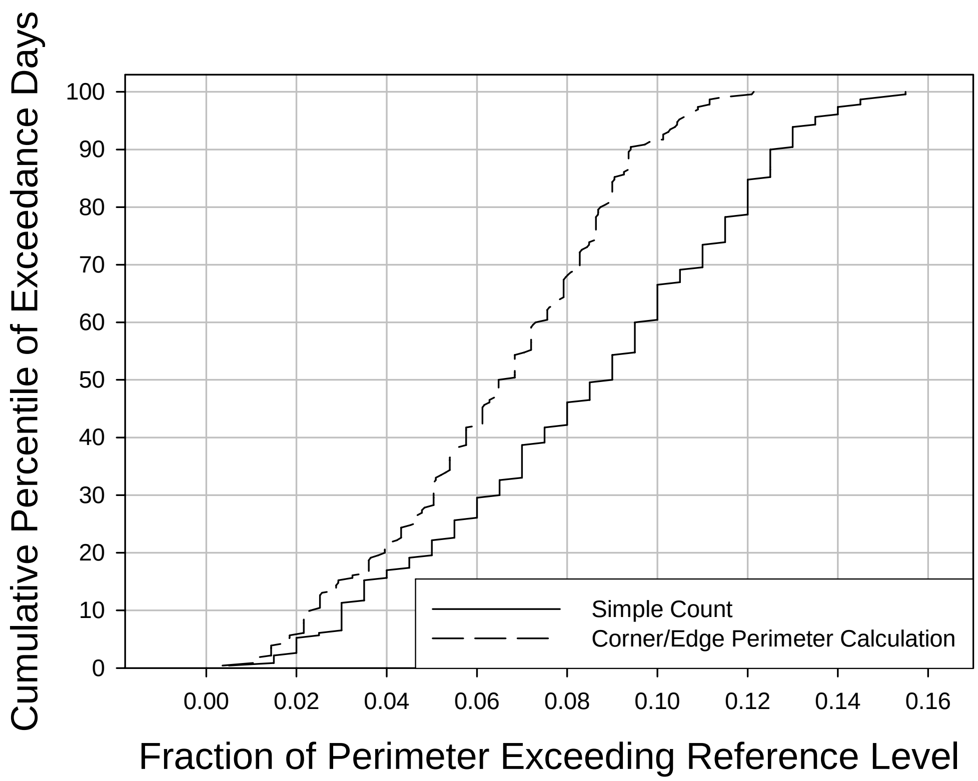

Figure E4. Cumulative distribution of perimeter length exceedances for 20 acre, fine grid scenario based on 230 days where at least one spoke exceeded the reference concentration at the buffer zone distance.

Appendix F. Procedure to compare the whole field buffer zone distributions with the maximum direction buffer zone distributions.

The whole field buffer zone distribution for each fumigant/application method/maximum application rate/meteorological data (scenario) combination was examined to find the 99% whole field buffer zone. Then for that same scenario the equivalent percentile at that buffer zone length in the maximum direction buffer zone distribution was found.

Results are presented by fumigant in the text of this memorandum. The tables below show an example of the PERFUM output used to locate the 99% whole field buffer zone length and the equivalent maximum direction buffer zone distribution percentile. Figure F1 illustrates the procedure graphically.

Table F1. Whole field buffer percentiles for an application rate of 250.0 for Flux Profile Day No. 1

Percentile	Buffer Zone(m)
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	5
60	5
65	10
70	20
75	30
80	45
85	65
90	95
95	145
97	185
99	290
99.9	590
99.99	1005

Table F2. Maximum concentration buffer percentiles for an application rate of 250.0 for Flux Profile Day No. 1

Percentile	Buffer Zone (m)
5	45
10	60
15	70
20	80
25	90
30	95
35	105
40	115
45	125
50	135
55	140
60	155
65	170
70	180
75	200
80	220
85	250
90	295
95	395
97	475
99	670
99.9	1225
99.99	1305

Figure F1. Illustration of the relationship between the 99% whole field buffer zone length and the equivalent maximum direction distribution percentile for the same buffer zone length.